A Peat Profile From Kettlehole Bog, Cass.

Thesis

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KETTLEHOLE BOG. CASS.

The samples were taken beside the post near the clump of Flax, halfway between centre and left edge.

Summary

A Pollen Analysis of a profile from the deepest part of the Kettlehole bog in the Cass Valley, Waimakariri River, yielded pollen which showed that there has been a change from grass-sedge association (with perhaps some trees), through a period when *Podocarps* formed one of the major elements of the forest, to the present predominantly *Nothofagus* forest. Inferences regarding climatic changes are not at variance with most results from other sources, except in that changes may have taken place earlier than believed by some workers.

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Introduction

To the ordinary man mires are not only lonely and monotonous but even uninteresting, and when one wanders for mile after mile over the unvarying surface of a bog it may seem difficult to dispel such an impression. But it is nevertheless a mistaken one. One has only to persevere to reveal a whole series of fascinating details, to discover that these mires mirror minor variations in climate, topography and soil conditions. That in fact the interplay of these factors makes its impress upon the history of the mire. (Oswald 1949)

Workers in many fields, such as Climate, Floral distribution, Archeology, Ecology, Soil, and Indicator fossils in oil searches, require a historical basis before they can understand their present problems fully. A knowledge of past floras is an important part of this history and can come from various sources. A macropaleontological study of the larger plant remains, such as leaves, stems, scales, and cones has yielded a great deal of valuable material. More recently micropaleontological examination of pollen and spores has proved an extremely abundant source of information. Ecology, the distribution of relic species, and a study of soil and geological processes are also important, if less prolific, sources. The most versatile field has proved to be analysis of the microfossils found in swamp, bog and lacustrine deposits. Extreme resistance to corrosion of pollen and spore walls has resulted in more representative fossils remaining than is the case with less durable plant parts.

Here pollen analysis is used as the main method in the elucidation of some aspects of the post-glacial floral and climatic history occurring in the Cass region of the Upper Waimakariri River valley.

History of Pollen Analysis

The presence of pollen in peats has been known for a great many years. Kirchheimer (1940) reported that Goppert and Ehrenberg had mentioned finding pollen in pre-Quaternary deposits as early as 1836 and 1838 respectively. The first systematic utilisation of pollen grains was apparently by C.A. Weber (1893) and his school. Their early records were purely qualitative. The first quantitative percentage calculations were carried out by Lagerheim (in Witte 1905) and later by Weber (1910). Lagerheims tables were used and quoted by N.O. Holst (1909) to support several ideas new to phytogeographers of his day, such as the disappearance of pine from Southern Sweden in historical times because of man's activities and the early migration of spruce from the South. His recommendation that investigation of microfossils could give a much more complete picture than one confined to macrofossils formed a basis on which pollen analysis now stands.

Wesenberg-Lund, one of the few of the time who foresaw the future of pollen analysis said "It may be reasonably anticipated that pollen investigations will play an everincreasing role in Quaternary Geology."

The foundations of modern pollen analysis were laid by L. Von Post who transformed this primitive pollen analysis into the refined method used in Quaternary research today. He was the first to present pollen diagrams and to use definite horizons to correlate the ages of different deposits.

Erdtman, who knew both Lagerheim and von Post well, considers that "Lagerheim (the spiritual father of modern pollen analysis) was truly a pioneer in micropaleontological and chemical-technical questions, while his pupil and co-worker von Post, a trained and keen-eyed peat stratigrapher, indicated how pollen analysis should be applied in order to give information on problems related to Quaternary geology and paleontology."

Erdtman publicised von Post's methods in a paper in 1921 and since this time they have been widely adopted. Some of the more prominent workers include Faegri and Iverson (Scandanavia), Firbas (Germany), Godwin's British group, and Erdtman and Wodehouse (pollen Morphologists).

In New Zealand, pollen analysis began with collections and analyses by Erdtman, in 1924 and 1925, from Otago, and the Chatham, Snares and Antipodes Islands. It continued with collections of peat samples from six localities by Carl c : zon Caldenius in 1933-4. L.Cranwell carried out a pollen analysis of these samples and then collaborated with von Post to work out a Post-glacial history of the

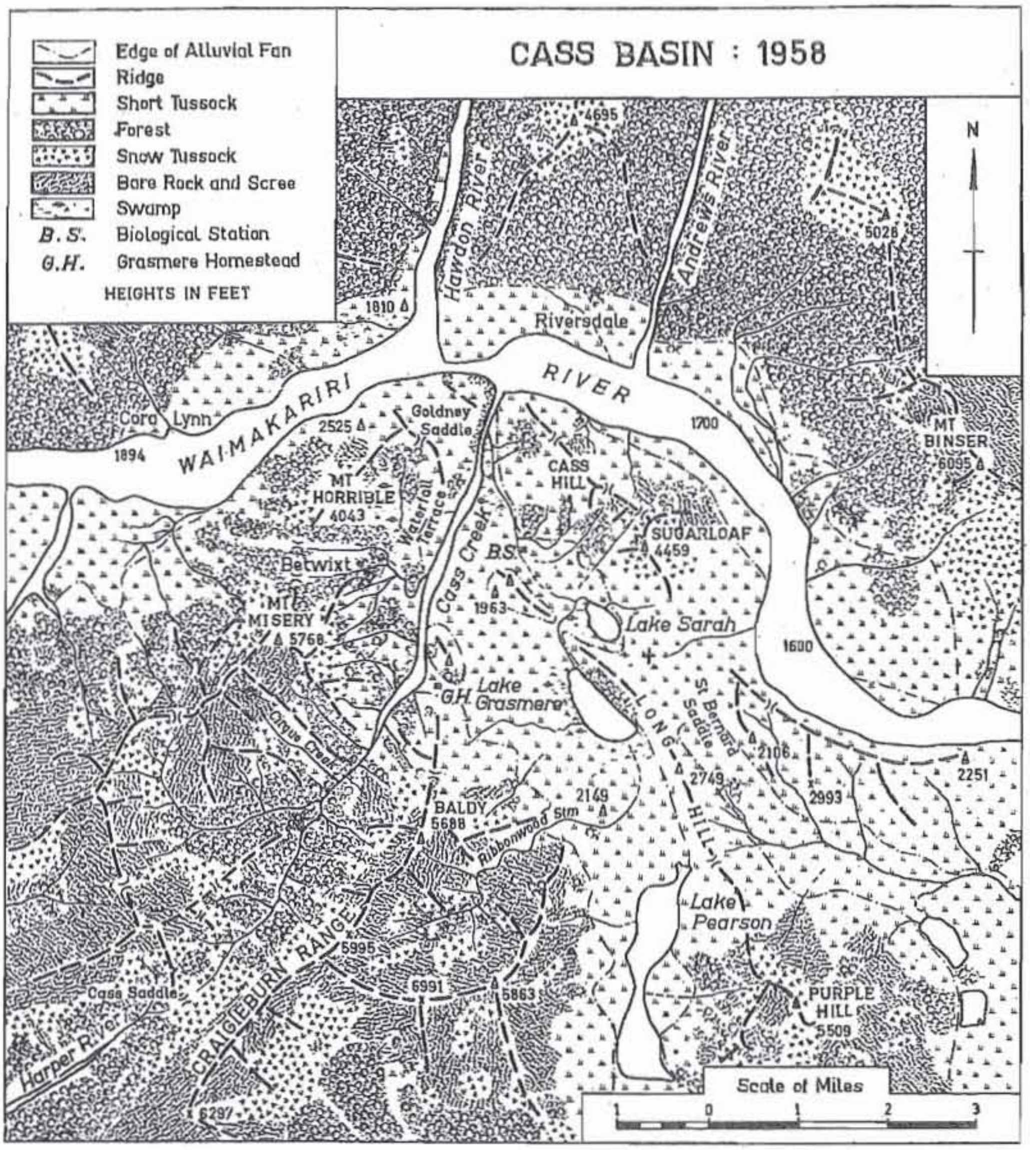
Southern part of the South Island.

Since Cranwell, several workers have carried out analyses of peat from wide-spread localities throughout the New Zealand region. W.F. Harris and D. Filmer studied a peat profile from the Hauraki Plains, and Harris has investigated Pyramid Valley deposits. R.A. Couper has contributed considerably to our knowledge of the earlier (Mesozoic) spores. N.T. Moar has published analyses from profiles in both the main and the outlying islands, and added considerably to the knowledge of the morphology of New Zealand pollens.

Map of the Cass Basin

(C.J. Burrows)

The small cross south-east of Lake Sarah marks the site of the bog.


CASS BASIN : 1958
Edge of Alluvial Fan
Ridge
Short Tussock
Forest
Snow Tussock
Bare Rock and Scree
Swamp
B.S. Biological Station
G.H. Grasmere Homestead
HEIGHTS IN FEET
N
WAIMAKARIRI RIVER
Hawdon River
Andrews River
Riversdale
Cora Lynn
1810
1894
1700
1600
4695
5026
MT BINSER 6095
2525
Goldney Saddle
MT HORRIBLE 4043
CASS HILL
SUGARLOAF 4459
Waterfall Terrace
Cass Creek
Betwixt
B.S.
1963
MT MISERY 5768
Lake Sarah
Lake Grasmere
G.H.
LONG HILL
St Bernard Saddle
2106
2251
2749
2993
2149
BALDY 5688
Ribbonwood Stm
Lake Pearson
PURPLE HILL 5509
CRAIGIEBURN RANGE
5995
6991
5863
6287
Cass Saddle
Harper River
Scale of Miles
1 0 1 2 3

The Bog and its Surroundings

The Waimakariri watershed is composed of folded and faulted Triassic indurated greywacke, siltstone, argillite, chert and volcanic rocks.

The mountains have been exposed to glacial advances corresponding to those occurring in the N. Hemisphere (Gage and Suggate). Gravels and moraines resulting from the retreat of these glaciers have formed huge deposits littering the floors of the valleys.

The Poulter Advance (Gage 1958) left a moraine on the St. Bernard Saddle containing massive blocks of ice which slowly melted. Their melting left depressions in the moraine, one of which, lacking drainage, became the Kettle-hole bog of this study. At first a small lake, it has gradually filled in with a predominantly organic deposit. Mineral matter - such as the loess carried by the North Westerly winds from surrounding mountains, has contributed only slightly to this deposit. The bog is fed by rainfall and drainage from the slopes of the moraine. A small stream flows from the lowest part down into the Waimakariri River.

The present flat surface (rising only 8") of the bog is covered with an even carpet consisting mainly of Sphagnum, but with other mosses in smaller numbers. Sedges and various herbs break the surface. Dissolution of the surface has resulted in the appearance of many open pools

A general view from above, showing the depressed Kettlehole Bog, surrounded by morainic banks.

which are slowly reinvaded by fresh growths of _Sphagnum_.

Principle of Pollen Analysis

There is no difference in principle between determining macrofossils such as seeds, twigs, leaves, etc. and determining microfossils, such as pollen grains and spores. There is however one major and important difference in that the microfossils dealt with in Pollen Analysis are comparable, and their relative frequency can therefore be expressed as a percentage of the total pollen. Macrofossils cannot be treated in this way, as a sum of, say, budscales, stems, etc., cannot be made. It is reasonable to say that a pollen rain consisted of 75% Nothofagus, 15% Phyllocladus, and 10% of grasses. Variations in the total percentage of different species can be followed through a vertical section of a peat bog or mire.

Before a pollen analysis is attempted one should understand clearly the scope of the investigation. This is important because, first, the total pollen counted will depend largely on whether one is attempting to discuss the general evidence of floristic change, or, the more detailed changes within plant communities which existed many years before the investigation was begun.

The total number of pollen grains counted will depend on which of these two problems one is attempting to solve.

If one is tracing general floristic changes fewer pollen grains can be counted than if one is investigating the more complex interplay between plant communities. For this latter it may be necessary to count many hundreds (or thousands) of grains in order that the pollen of less well represented species should be detected.

When the problem is clear, and the pollen count is completed, one must then consider which species should be used as a basis for the calculations. This depends on the particular problem and when general floristic changes, e.g. of forests are sought, the calculations are based on the total forest pollen counted. Other species, shrubs or ferns, etc., are usually calculated as a percentage of the pollen sum.

This general principle is not to be regarded as inflexible. The Sub-Antarctic Islands within the New Zealand region, e.g. Aucklands, Campbell, Snares, Antipodes - islands blanketed with peat, results can but be presented by including all pollen grains noted within the pollen count (Harris, Moar)

In the region of this work it is the history of the forests, the dominant features of the vegetation, which is stressed, so only arboreal pollen is used in the total sum. Ferns, herbs and shrubs are calculated as percentages of this sum.

An analysis of peat to give a picture of the past history of a region follows the following pattern:
Suitable bogs are selected, surveyed, and samples taken from points on a transect through the deepest parts. The

samples are treated to extract the pollen, this is mounted, and the types represented listed and counted. These are expressed as perceatages and plotted on diagrams. Variations in the curves show vegetational changes which can be correlated to climatic and other changes. These steps will be dealt with fully in following chapters.

Sources of error.

Various errors can distort pollen diagrams. The ever present dangers of all stratigraphical work - viz erosion and redeposition are usually fairly obvious in pollen analytical work because they will show as an abrupt discontinuity on the pollen diagram. Erosion is unlikely to occur in a Kettlehole bog. Redeposition from the erosion of some older deposit could conceivably take place, butthe glacial ice-sheet would probably remove any pre-glacial peat. Where redeposition has occured the material removed is usually spread over such a wide area that contamination is negligible (Faegri and Iverson 1950). There is no evidence of either error in the profile which is the basis of this study.

Errors peculiar to pollen analysis have been long known. An early cause of anxiety, since shown to be without significance (Malmström 1923), was downwash of pollen grains. He showed that pollen grains of Lilium bulbiferum sprinkled on a bog are washed through unconsolidated litter but do not penetrate peat at all. Erdtman (1921) showed that the pollen spectra of living Sphagnum cushions was identical with that of mosses on rocks and stumps where downwash was impossible. With this evidence in mind, the possibility that tree pollens may have been carried down to immediate post glacial deposits in this profile is discounted.

Over-representation of one or more species is another persistent problem. Plants of the mother formation of the peat would presumably deposit large quantities of pollen on the surface immediately below. For this reason, at least locally, non-arboreal species are likely to be the greatest offenders. In this profile over-representation of these species does not seem to be present, but there is a strong possibility that the high maxima shown by the shrubs Dacrydium biforme and D. bidwillii is at least partly attributable to this cause.

Long distance transport of pollen can lead to serious error in the interpretation of pollen diagrams. Arboreal pollen can be blown great distances. Polunin (1951) has shown that pollen can travel enormous distances. Erdtman found Nothofagus pollen in the Chathams, 300 miles from the nearest source, and Moar had similar experience with pollen from the subantarctic Islands. Faegri and Iverson (1950) consider that long distance Arboreal pollen may be present normally up to 5% of the total pollen. This contamination is negligible when high A.P. counts are made, but when A.P. is scanty, as at the bottom of this profile, it becomes a serious factor. However there is evidence that the effect from vegetation outside a given community may be much less than one might expect. Jonassen (1950) came to the conclusion that forest pollen spectra were very local in character: in other words they predominantly determine the vegetation on the site. Recent work on the spread of pollen from the parent trees accords with this conclusion. Bluell (1947) studying Pinus banksiana found that at a quarter of a mile from the forest the pine pollen rain is only 10% of that within the forest. Wright (1953) shows Bluell's results are true of a wider number of species.

The presence of low frequencies of one species, for example Podocarpus dacrydioides in this deposit, also poses the problem whether it was actually present in the local flora, or is merely from distant regions. Without macroscopic evidence it is impossible to be certain one way or the other in such cases.

Destruction and corrosion of the pollen of a species can lead to its absence or under-representation. Libocedrus pollen for example is unknown in New Zealand peat and presumably illustrates this type of error.

As Pollen Analysis is basically statistical in its methods; it is prone to the errors inherent in all statistical techniques.

Two types of statistical problems are of interest to pollen analysis. These are:-

1. Sampling errors. It is obvious that the greater the number of samples analysed, and the number of grains

counted in each sample, the more accurate the result will be. For practical purposes it has been found to be sufficient if samples are analysed at 5cm intervals in a profile. Intermediate checks can be undertaken if made necessary by abrupt discontinuities. A Minimum of 150 A.P. grains should be counted to give reliable curves. (In this analysis ca 200 A.P. were counted.) Barkley (1934) reports that there is little significant shifting of the relative percentages beyond the 200 mark.

2. Irregular fluctuations of the curves, which interfere with and obscure long-term trends which are of prime interest in the investigation. This includes sudden peaks, which if "real" and not local, are of extreme importance in the synchronisation of the diagram with diagrams from other localities. Faegri and Ottestad (1948) deal with a mathematical method of indicating the true value of such peaks. However as the method is both complex and can be used as a negative test only, it was not attempted. Faegri and Iverson (1950) point out that longtime movements are usually fairly obvious and make complex statistical methods unnecessary. They warn of the numerous dangers and pitfalls attendant on the uncritical application of statistical formulae by workers unversed in the methods required. In these diagrams peaks are recorded and interpreted botanically and without recourse to statistical theory.

Peat and Macroscopic Remains.

Profiles from four bores were examined. The deepest bore is described here in detail, the other three being used for verification and to give a picture of the bog's stratigraphy (see Table 1)

The upper 20 cm of the peat consists of recently formed material - mainly unhumified and much of it still living. It appears much disturbed and traces of charcoal show that it has been exposed to fire at some recent time. Stock would also presumably alter the surface to some extent. For these reasons careful examination started where the peat seemed reasonably stable and consolidated. Down to 28 cm it was black and similar to the surface.

From the surface down to 60 cm there is a zone which could be described as a Sphagnum peat, because although sedge remains are plentiful, Sphagnum appears to form the bulk of the material. It could be called a Carex-Sphagnum peat. However, as Harris and Filmer (1946) point out, almost all the Sphagnum would be preserved because of its subaerial habit, while only the smaller part - the root system - of Carex or Schoenus, would survive. In this case, to follow the above authors - the peat would fall into their:-

Division I Macromorphic Peats
Class II Herbaceous Peats

Series Tall monocotylous herb
Type _Carex_ community

From 60 - 240 cm. is a layer of peat which appears at first to be homogenous in structure. Probing produced the information that within this large stratum was a smaller diffuse one of wood fragments. The recognisable plant fragments consist mainly of _Schoenus Pauciflorus_ remains - characteristic leaf bases, utricles, etc. _Sphagnum_ remains are not visible in the raw peat, but show up in a microscopical examination. The density of the wood layer in some parts made penetration with the auger difficult. It was not possible to decide whether it was a mat of smaller branches or of larger logs. A hole dug to a depth of four feet six inches during a dry summer disclosed a tangled weft of gnarled branches up to three inches in diameter. Deeper unattainable remains felt larger than this, and some could have been up to eighteen inches in diameter. The wood has been tentatively identified as _Discaria_.

Using Harris and Filmer's classification could give:-

Division I Macromorphic peats
Class II Herbaceous peats
Series Tall monocotylous herb
Type Sedge (Schoenus Pauciflorus) peat.
and

Division I Macromorphic peats
Class III Woody Peats
Series Shrub or forest
Type Discaria community peat

Below this was a layer of light grey-yellow coloured almost totally humified peat containing no recognisable macroscopic remains. This organic mud oxidised rapidly within a few minutes to a blackish form. It would be classified as a :-

Division II Micromorphic peat
Class V Limnic peats
Series - Non-mineral

Presumably this peat was formed under lacustrine conditions.

The remaining peat is not easy to classify. It contains a few monocotylous fragments (sedges), a small piece of wood, a crucifer seed, and Sphagnum remains, It is possibly Harris and Filmer's Class VI - Emerged peat.

Cranwell (1949) proposed a classification of bogs. This particular bog does not conform very closely to any of her types, but appears to be at present in the upper part a paludification bog. Soligenous, with much Sphagnum, and maintained by rain with a little drainage from surrounding slopes. It is sensitive to drying, fire and stock, breaking down to open pools readily.

The history of the bog could be:-

I Sedimentary - deposited in lake formed by melting of ice and rise in water level. A "Gyttja" deposit.

II Sedentary - an inundation topogenous bog (Cranwell and Moore) leading to a type of paludification bog, although it is doubtful if the rainfall is high enough for true blanket bog.

The possibility suggested by Cranwell and Raeside that there was formerly a higher rainfall from the East in post-glacial times could be reflected in the growth pattern of this bog.

Depth.	Colour.	Humif.	Wetness	Mineral.	Remarks.
22-28	Black	H9	4	-	Roots of surface plants, Sphagnum
29-33	V.dark grey brown 10YR 3/2	7	3-4	slight	Roots and Sphagnum more frequent
34-58	10YR 3/2	7	3	slight	Roots of Carex, Sphagnum Surface of above mineralized by drainage from surrounding slopes, well oxidised
59-83	10YR 3/3	6-7	3	light	slightly fibrous, sedge remains, no Sphagnum
84-108	10YR 3/3	4	3	moderate	Sedge peat, many fragments
109-133	10YR 3/3	4	4	slight	Sedge peat, seeds, moss capsule
134-158	10YR 3/2	5	4	moderate	Sedge peat, Schoenus, seeds, wood trace.
159-183	10YR 3/3	7	3	-	Sedge fragments, seeds, wood, texture more jelly-like.
184-208	10YR 3/3	8	3	-	Sedge fragments, Eleocarpus seed.
209-233	2.5Y 4/2 olive-brown	8	3	slight	Sedge fragments.
234-258	2.5Y 4/4	9	3	slight	Organic mud, few sedge fragments.
259-283	5Y 4/2	9	3	v.slight	Organic mud, few sedge fragments.
284-308	5Y 4/2-4/3	9	3	moderate	Very plastic organic mud, trace sedge.
309-333	5Y4/3-2.5Y4/4	9	3	sandmod.	Organic mud-sandy peat. Change at 323cm.
334-358	2.5Y4/4-5Y5/2	9	2	sand-clay	Sandy peat.
				considerable	Banded profile, sandy, mostly with clay.
				much	Small stones throughout- glacial shingle

The Pollen Diagram

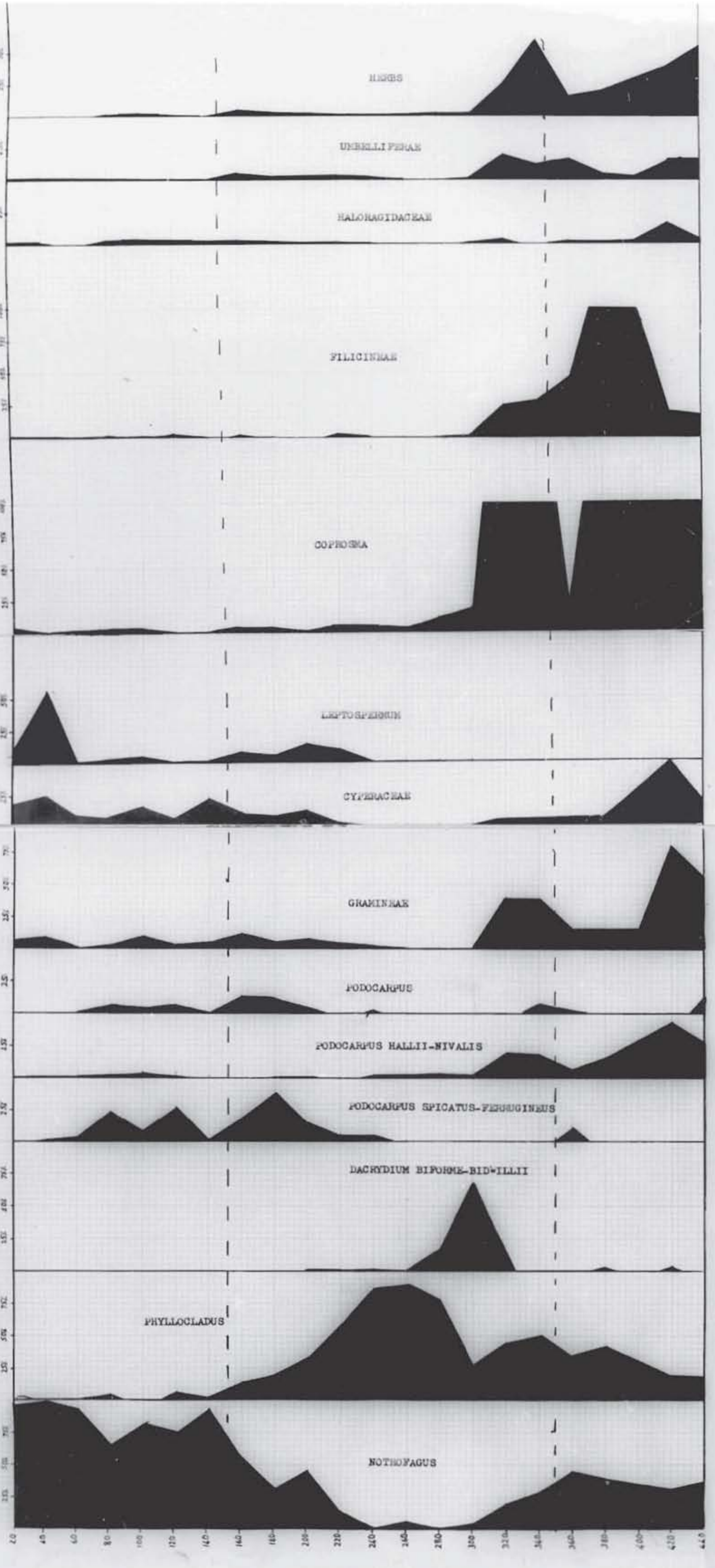
The Pollen diagram shows no sudden changes overall, although there are some spectacular local peaks.

Nothofagus is the only arboreal pollen present throughout the profile, unless the Podocarp pollen is plotted as one Podocarpoid type, a practice followed in some of the earlier work. There is a decease in its frequency between 2 and 3 metres, but this could be, as is discussed elsewhere, because of over-representation of Phyllocladus and Dacrydium pollen.

The diagram differs somewhat from earlier results from other localities, (Cranwell, Harris and Filmer, Moar) in that the Podocarps are nowhere more than transitorily dominant. Most of the above quoted diagrams show, if they cover a sufficient range, a trend from an early association characterised by a sparsity of arboreal types, through a Podocarp dominant period to a Nothofagus dominant period still existing. If Phyllocladus is substituted for, or included with, Podocarpus spp., then the diagram conforms, broadly speaking, with the usual pattern established for New Zealand post-glacial succession.

There are minor fluctuations in the curves which could represent climatic changes, but until other profiles from other bogs in the region show similar variations, it is unsafe to place too much emphasis on their interpretation. An attempt will be made later to compare some of the larger

The Pollen Diagram



HERBS
UMBELLIFERAE
HALORAGIDACEAE
FILICINEAE
COPROSMA
LEPTOSPERMUM
CYPERACEAE
GRAMINEAE
PODOCARPUS
PODOCARPUS HALLII-NIVALIS
PODOCARPUS SPICATUS-FERRUGINEUS
DACRYDIUM BIFORME-BIDWILLII
PHYLLOCLADUS
NOTHOFAGUS
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440

features with some of the features exhibited by British examples, but it must be emphasized that any such correlations will be purely tentative.

Smaller zones, e.g. where Phyllocladus is dominant, could be used, as they are in European work, to establish a standard sequence, but no definite zonation pattern for the few New Zealand profiles so far described, has emerged.

The diagram shows an early period when Nothofagus and Podocarpoid types were both present, but quantitatively sparse, along with shrubs, grasses and sedges. This would correspond to Cranwell and von Post 1936 Zone I. Their Zone II, in this diagram, would be that area between 150cm and 350cm where Gymnosperms are the most numerous, and Zone III, from 350cm to the surface, with Nothofagus as the predominant type. The initiation of a trend is taken as the beginning of a zone.

Pollen Types

A pollen analysis cannot be attempted unless one can identify the pollen types encountered.

The morphology of pollen grains has been studied for many years e.g. Fritsche (1837) and Fischer (1890) and Edgeworth (1879). The more recent works of Wodehouse (1938) and Erdtman (1943, 1952) should be consulted always and for New Zealand studies there are available publications by Cranwell (1938, 1940, 1942 and 1953), Harris (1953, 1955) and Moar (1959 1960). Cookson's work on beeches has caused Couper to change some of his earlier diagrams because his species seem to be identical with some fossil Nothofagus previously described. She also has discussed conifers.

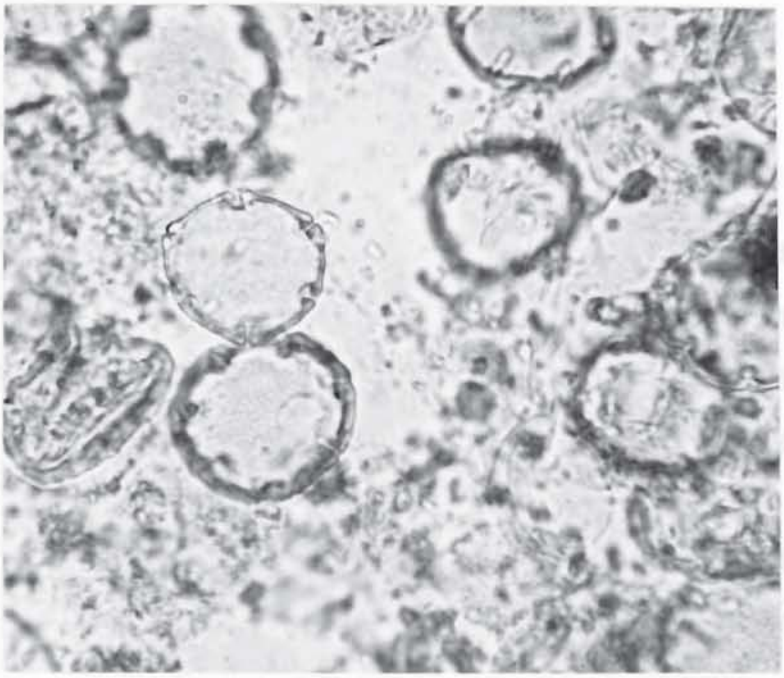
The pollen grains of the Gymnosperms, the monocotyledons and the dicotyledons are usually easily distinguished from each other. (see Pollen plates) In many cases identification can be made at the species level. Fern spores are also easily separated from the three groups mentioned above. In order that the descriptions of the pollen types encountered may be understood, a brief account of pollen morphology is necessary.

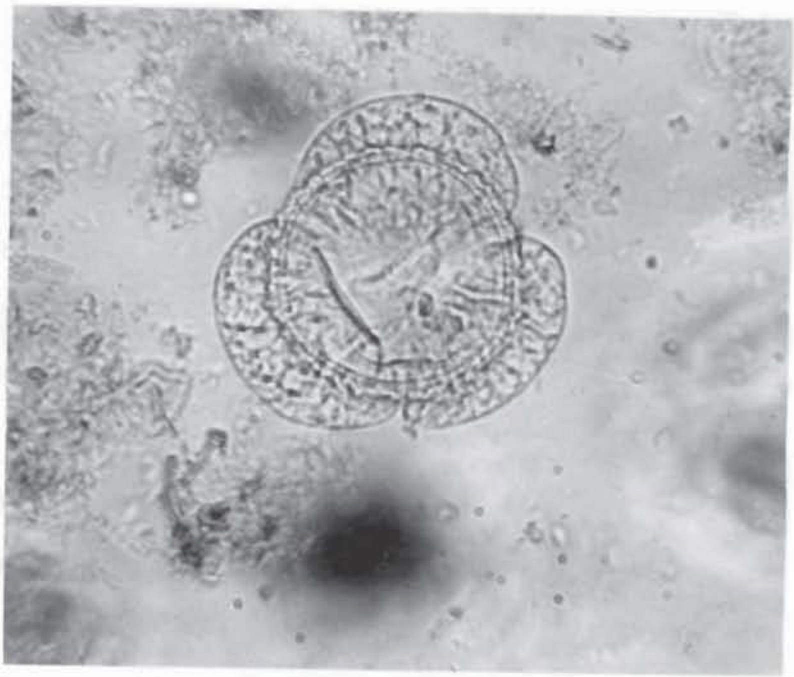
Although there is great variation in size, shape and pattern, a basic structure common to all grains can be described. This is:

1. The outer wall, or exine, which is divided into

Nothofagus sp.

Podocarpus dacrydiodes.





ectexine and endexine. The ectexine may occur as simple rods external to the endexine (intectate), or as a more complex structure, when the tops of the rods fuse to form a continuous or discontinuous roof (tectate). This roof is the tectum, and may develop spines or rods, as in the Compositae and Malvaceae, which add to the complexity of the pollen grain.

The endexine is a structureless layer, although Erdtman (1950) claims that two layers, an extonexine and an endonexine, can be distinguished.

2. The Intine, a delicate layer within the endexine, surrounds the cytoplasm and is destroyed by fossilisation and most of the usual methods of preparing and mounting pollen grains.

Nothofagus. Cranwell (1938) described the pollen grains of the New Zealand species of Nothofagus. Further work has been published by Cookson (1947) and Harris (1956). These studies have added much to our knowledge of the morphology of Nothofagus pollen, but for all practical purposes the only species which can readily be distinguished is that of N. menziesii. This pollen type was not observed in this study.

Von Post (1929) pointed out the possibility of using statistics of aperture numbers to elucidate changes in the pollen rain recorded in peat profiles.

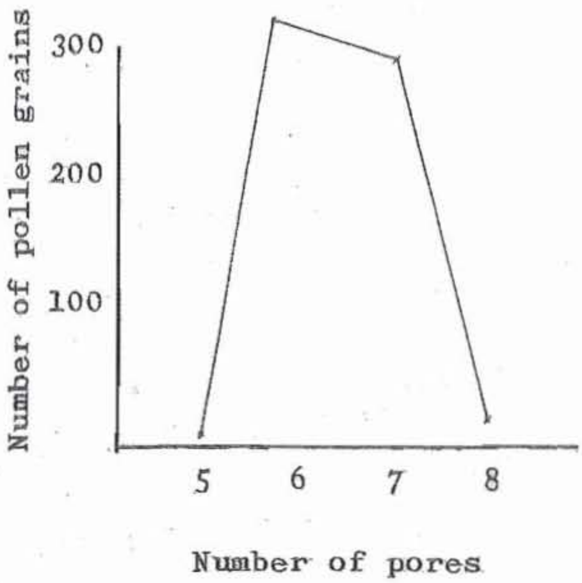
Cranwell considered this but did not provide a key.

She noted that pollen of N. fusca stands out from remaining species in respect to size and aperture number, and that the exine of N. Cliffortioides is more strongly sculptured, but feared that hybridism would tend to mask the small differences.

Harris (1956) points out that there is some correlation between size and aperture number within a species, but this correlation does not hold between species. Both historically and geographically pollen grain characters, such as sculpture of the exine, number of apertures and size show independent variation.

Direct comparison of sculpture and thickness of the exine will distinguish between N. cliffortioides and N. solandri, but Poole says that these two species grade imperceptibly into each other and now regards them as a single species (Poole 1958). As the average size of truncata is bigger, some segregation on size and aperture is possible. The pollen encountered in this profile fitted Harris's description of the N. fusca group, which includes N. cliffortioides. "Pollen free, isopolar, bilateral or asymmetrical 5-8 aperturate, apertures predominantly 7, colpoid, equatorial and slitlike, meridionally elongate, exine invaginated and surrounded by an inner hyaline collarlike thickening. Shape spherical or elongate in polar view and either elliptical with outline convex between the apertures, or polygonal and angulaperturate with outline straight between the angles, S.E. : L.E. 7.4 : 8, oblate and elliptical in

Podocarpus spicatus/ferrugineus



Graph to show that there is no separation into species using number of pores.

lateral view, P:E average 6.2 : 8. Exine thin, consisting of a very thin ectexine which is scabrate with minute rather pointed surface granules and a thicker endexine."

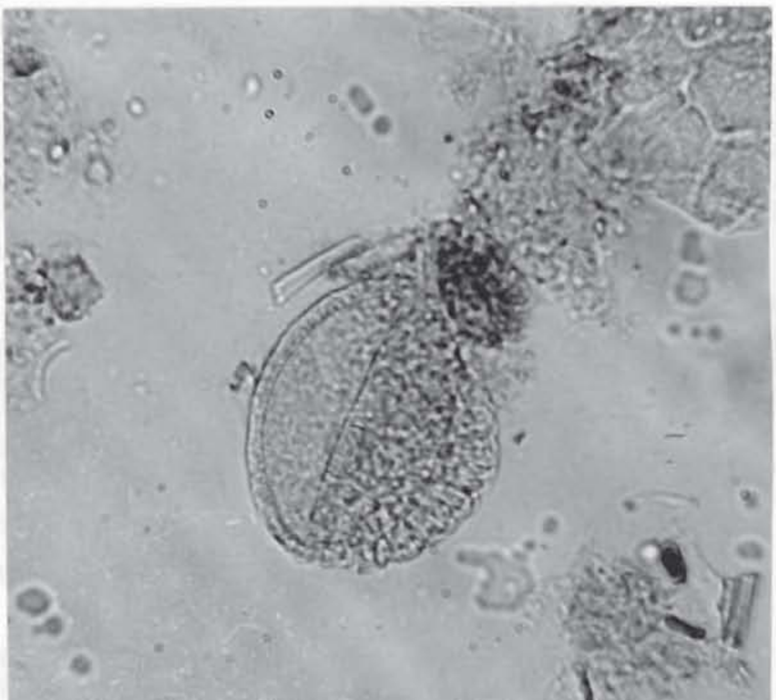
The Nothofagus spp. pollen grains in some specimens of peat were tested to see if any separation into species was possible. Size or aperture number was plotted against frequency of occurrence. In both cases the graphs obtained showed single peaks - no separation was possible on these characters. (see graph)

Podocarpus, Dacrydium and Phyllocladus. (Taxaceae)

Erdtman gives the following general description of Podocarpus pollen : Grains more or less spheroidal, provided with two or three well defined bladders, or with bladdery projections 23-39 u diameter. Furrow usually long, its boundaries sharply delineated by an abrupt change in texture and a rather pronounced thickening along its rim. Bladders usually large and spreading, but tending to be weak and flaccid. Smooth outer surface but conspicuously marked inside by reticualte thickenings. At their proximal roots their texture merges with that of the cap at its margin, which is sometimes developed as a marginal crest.

Cranwell (1942) separates the species into groups on two main characters - bladder markings and furrow shape. Those with elongate furrows and coarse radial bladder thickenings include :

Podocarpus hallii-nivalis



Dacrydium kirkii, D. biforme, D. bidwillii.

Those with elongate furrows, delicate reticulate thickenings and a pitted cap include : Podocarpus totara, P. hallii, P. spicatus, P. ferrugineus.

With rudimentary bladders and radial thickenings Dacrydium cupressinum with rudimentary bladders forming frills projecting little beyond the body of the pollen grain Phyllocladus alpinus.

Couper (1953) separates them a little further. His key is

"1. Bladders with reticulate thickenings

A. Marginal ridge prominent, exine of proximal cap 2u or more thick and coarsely sculptured - Podocarpus.

a. grains ellipsoidal to circular in polar view

1. disaccate — P.nivalis, P.totara, P.hallii, P.acutifolius

Trisaccate — P.dacrydioides

b. Grains usually clearly angled

I. Reticulation of the bladders very clear, muri forming complete polygons — P.spicatus

II. Reticulation of bladders very clear, but muri forming an open blindly branching system — P. ferrugineus

B. Marginal ridge not prominent, exine of proximal cap 2u or less finely sculptured grains angled (rhomboidal) Dacrydium

a. 40u or over — D.intermedium

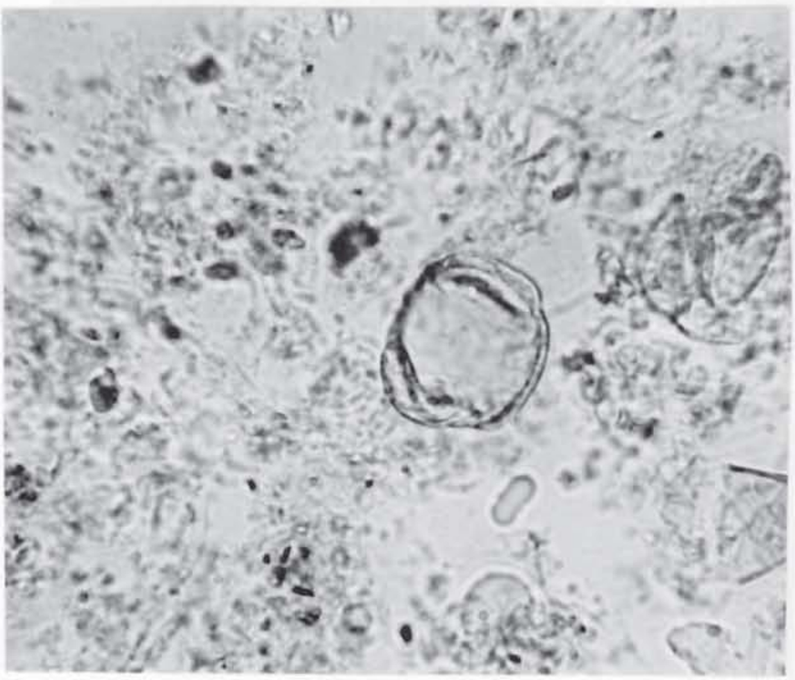
b. usually less than 40u — D.colensoi, D.laxifolium

2 Bladders with radial thickenings

A Bladders rudimentary, tend to merge — D.cupressinum

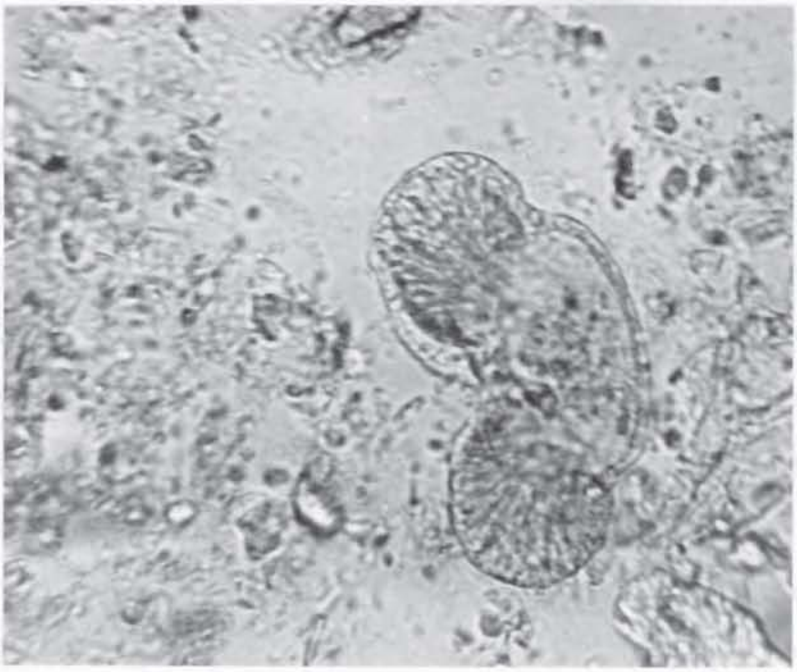
B Bladders two, clearly defined, large — D. kirkii, D. biforme, D.bidwillii

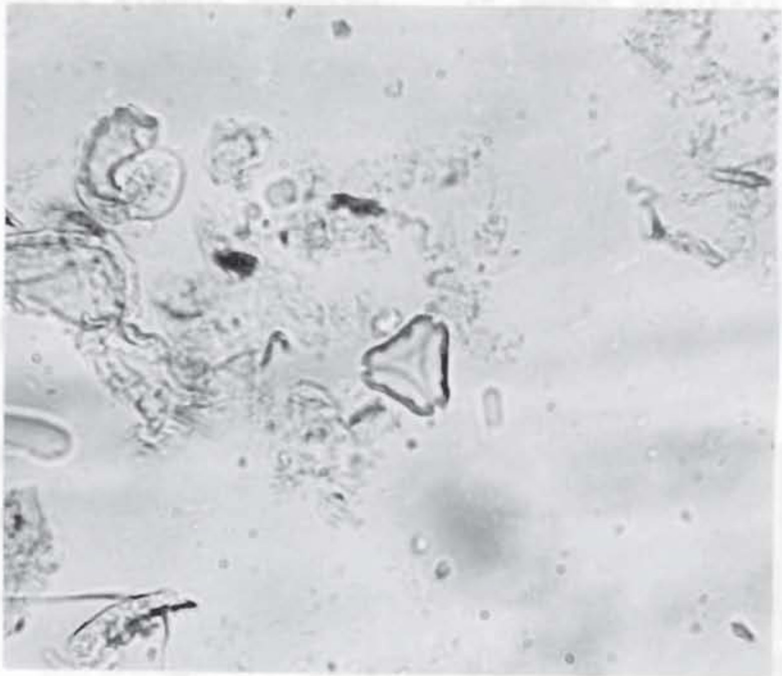
Phyllocladus alpinus



Dacrydium biforme-bidwillii

Leptospermum sp.





Moar has recently investigated the finer structure of the exine of Podocarpaceae. In unpublished work he has shown that it is possible to identify N.Z. spp. of Podocarpus to the species level and that similar results may be expected in Dacrydium. His methods were only partly used in this thesis so that most species are grouped together as in Couper's key. Fossilisation causes collapse of the bladders in many cases so that definite identification is impossible.

From the preceding notes it is obvious that the Taxaceae are a difficult group for the pollen analyst. Martin (1959) investigating South African Podocarps, sums this up as follows: "Statistical data suggest that there is considerable variability in pollen size and pollen proportions, both within and between populations of a single species. It seems unlikely that this variability has any relationship to geographical locality - - for example in Podocarpus latifolius the largest grains (collection No. 2, mean length 43.5u) and the smallest grains (collection No. 10, mean length 35.6u) were found from two trees growing within a few yards of each other in forest near Grahamstown."

"An analysis of variance shows that the South African species fall into three distinguishable groups."

Other important pollen types encountered are briefly described.

Cyperaceae. (Although the pollen grains of this family and pollen grains in general are not homologous (Selling 1947) they can be considered so for purposes of identification.)

Cyperaceae

Gramineae

Elongate to spheroidal. 30-60u, exine very thin, pale in colour, faintly granular. Pores weak or obscure.

Gramineae. Spheroidal to ovoid, 20-50u, exine pilate or reticulate, sometimes tegillate. Aperture 1, protruding, crassimarginate, operculate.

Cranwell and von Post (1936) showed that grasses could be distinguished to some extent on size and pore characteristics into (a) a Danthonia raoulii type representing cold and wet areas, and (b) a Poa caespitosa and a Festuca novae-zelandiae type, the dominant of existing low-tussock grassland ("dry steppe").

Geisler (1945) found that she was unable to use size as a guide to identification of American grass pollens.

Erdtman (1943) quotes American workers who have used a high proportion of grass pollen as evidence of xerothermic periods. Keller (1943) investigated this claim and found that the present prairie grasses all have pollen larger than that from fossil beds. They conclude that grass pollen has no use as an indicator of any particular climatic conditions.

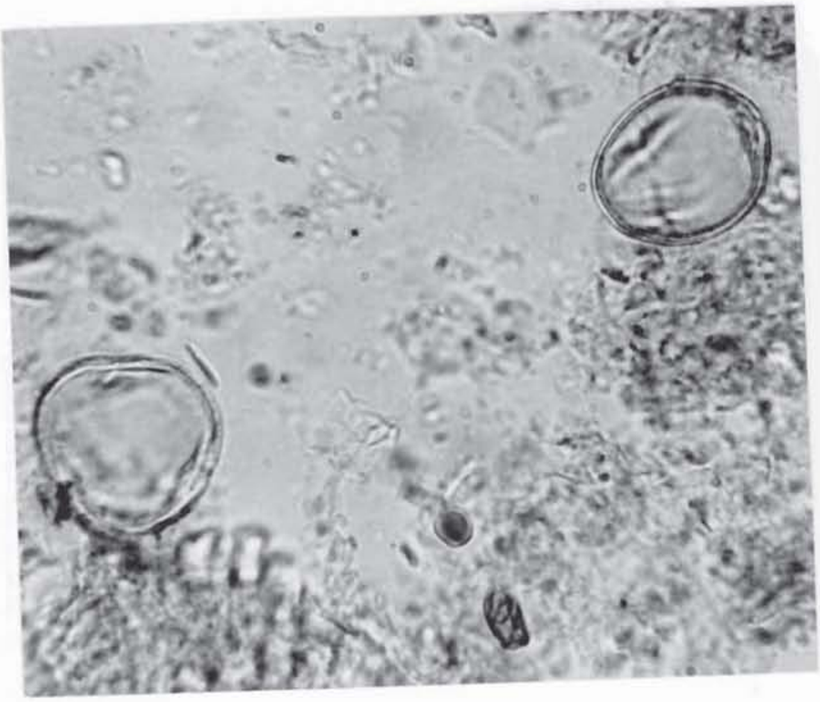
Recent work suggests that phase contrast microscopy may help in separating the Pollen of the major groups among the grasses.

In this study the grasses are listed only, and no attempt to separate species was made.

Many other genera were represented by small numbers of pollen grains, which, although interesting, do not affect the overall picture given by the main types described above.

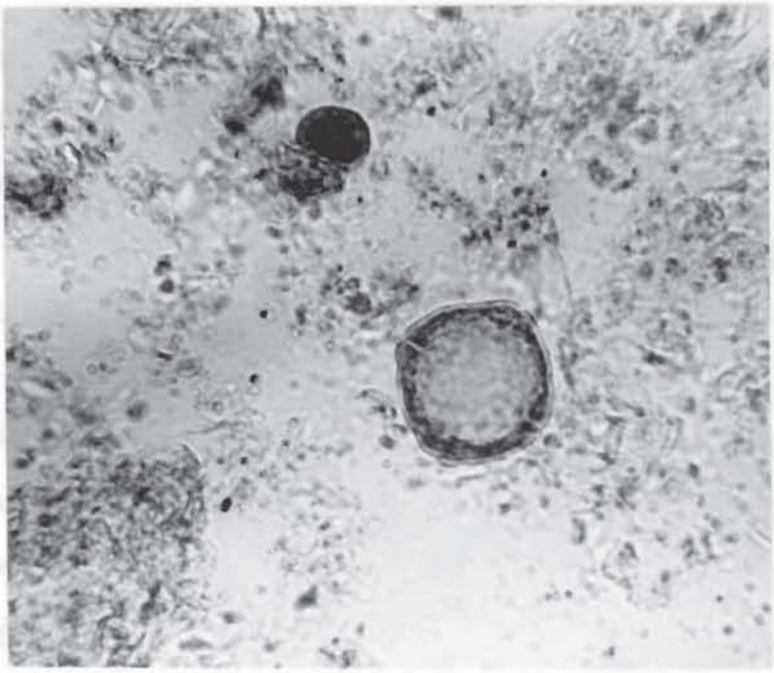
Coprosma

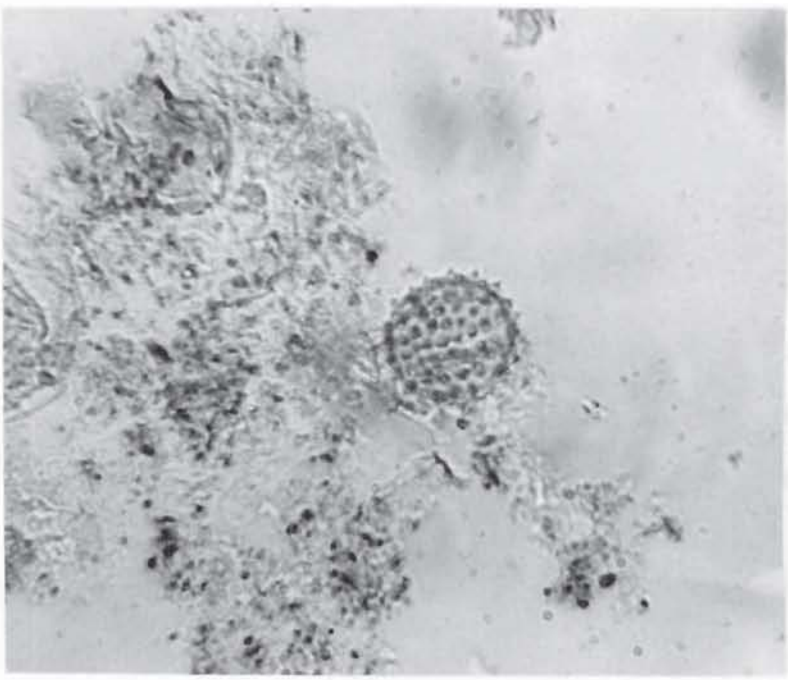
Umbelliferae



Haloragidaceae

Compositae





Descriptions of these genera are not given here, but can be found in Wodehouse (1935), Cranwell (1942) and Erdtman (1952).

Some shrubs, notably Coprosma and Leptospermum, are prolific at some points on the profile. Herbs are never well represented presumably because they are mostly entomophilous and produce little pollen to be dispersed. Shrubs and Herbs encountered included Ranunculus spp., various Umbellifers, Haloragis spp. and Gunnera sp., Suttonia sp., Elytranthe sp., some Rosaceae, some Compositae, Ascarina sp., some Araliaceae, Astelia sp., Chrysobactron sp. Metrosideros sp., Pittosporum sp. (doubtful), and Dracophyllum sp. (doubtful).

Many ferns were represented by spores, and included the following: Blechnum spp., Cyathea spp. (probably C. Smithii Hypolepis millifolium, Mecodium villosum, Hymenophyllum spp., Microsorium diversifolium, Asplenium sp., and Polystichum sp

Other spores encountered included those of Sphagnum sp., Lycopodium sp., and fungal spores. Some attempt to classify the latter in the hope that they could indicate the presence of hosts (Rusts - Cunningham 1931) led to no really definite results as detail was insufficient in fossilised material. Sooty moulds (Capnodiaceae) which indicate the presence of Nothofagus, were common.

Ecological notes on main species.

The pollen diagrams indicate a succession of plant communities:

1. An early period when there was more grass than later, much *Coprosma*, and both *Nothofagus* and *Podocarpus spp.* present.
2. A Podocarp dominant period
3. A *Nothofagus* dominant period.

The interpretation of this succession depends on an understanding of the ecology of the major species or genera represented in the pollen diagrams.

1. *Nothofagus*. The genus in New Zealand covers a wide range of ecological conditions. As stated in an earlier section the species represented in pollen diagrams is probably *Nothofagus cliffortioides*. According to many authors (Cockayne 1926 - 28, Allen 1926, Cranwell and von Post 1936, Holloway 1949 and 1954), *N. cliffortioides* is indicative of cool and relatively dry climates.

Holloway (1949) shows that regeneration of *N. cliffortioides* can occur in regions where the rainfall is as low as 25" per annum. In most of its range however the annual rainfall is higher. Cass has a rainfall of 50" per annum, Bealey in the Waimakariri Valley about ten miles away has 60" annually and Arthur's Pass near the main divide has almost 200" per annum. Where an area contains a mixture of forest types, *N. cliffortioides* is always found on

the higher and drier ridges, while those species demanding more favourable conditions are found on the sheltered and damper slopes and valley floors. To mention one renowned example Allen (1926) in his account of the Mt. Peel forest described the following sequence of forest trees.
On the flood plain of the Rangitata River Podocarpus dacrydioides is dominant with occasional P. spicatus and P. Totara. The forest on the terraces has P. spicatus as the most abundant type with some P. totara. Above on the drier slopes P. totara is dominant until well up where it is replaced by Metrosideros umbellata. Finally above this, and descending down the coursed of streams from whence it has spread to dry mid slopes and rocky knolls is N. cliffortioides.

Invasion of new territory by N. cliffortioides is slow. Poole (1953) and Holloway (1954) both emphasize that migration is as a wall of forest. The seed is heavy and can only be carried any distance by streams, and Poole also notes that seedlings only grow in close proximity to mature trees. Displacement of Nothofagus over large areas by Podocarpus spp. could result in small pockets remaining in less favourable areas.

Podocarpus. Cockayne (1928) points out the wide variety of ecological niches occupied by the genus.

In Canterbury P. totara is found on hillsides which are wetter and warmer than is required by N. cliffortioides, but too dry for most of the low land Podocarps.

P. hallii is often associated with P. totara but usually occupies areas which are colder, wetter, and have more shallow soil.

P. nivalis occurs on well drained windswept mountain slopes where the soil is poor and stony. It is a common shrub on unstable mountainsides.

P. spicatus is considered an important climatic indicator species by Holloway (1954). His forest survey found that small pockets or even isolated specimens of matai (P. spicatus) occur throughout the length of the Island east of the Alps. P. spicatus, P. totara, and to a lesser extent P. dacrydioides are the physiognomic species of these forest pockets. They show no particular edaphic requirements, occurring on soils derived from a variety of rock types. However in most of these pockets none of these species is reproducing and most of the trees are old and overmature, apparently because climatic conditions are below the optimum needed for regeneration. Conditions where seedlings, saplings, and poles are now found e.g. North Island forests, are considerably warmer and wetter than those now existing in the South Island in this region. It is not too much to say that forests composed of these species came into being under such conditions.

P. ferrugineus favours similar or wetter conditions than P. spicatus. Its closest occurrence to Cass now is in the Otira Valley in a 200" rainfall region where it associates with P. Spicatus and P. dacrydioides Dacrydium biforme and D. bidwillii are characteristic of cool and very wet conditions. Wardle (1960) states that D. biforme is conspicuous where soils are poorly drained and cold in the Hokitika Catchment. It is now the dominant tree in one of the subalpine scrub-zones of Westland in a 300" rainfall region. Cockayne (1928) in his description of Cupressoid-podocarpus scrub says "scrub of this type is usually D. biforme or bidwillii dominant. Apparently it is commonest on boggy windswept, or poor stony soil. Near Mt. Cook on old moraine D. bidwillii is dominant. Associated with it are Phyllocladus alpinus, P. nivalis, Aristotelia fruticosa and Coprosma spp."

Phyllocladus alpinus forms a definite zone between mountain beech and subalpine scrubs. Somewhat colder and wetter conditions than those required by N. cliffortioides represent optimum conditions fob it.

Leptospermum scoparium appears able to grow under almost any edaphic conditions from bog to dry stony plains. Cockayne (1928) describes it in all these circumstances e.g. page 180 On bog - - - - - the first arrival being L. Scoparium and in its shade various species can be established.
Bog forest - - - - - L. scoparium may be dominant and accommpanied by P. nivalis, P. alpinus etc.
P. 189 Leptospermum bog land - - - - vast numbers of seedlings grow and kill each other out - - survivors branch

and let in light - - other species enter.

P. 193 Canterbury Leptospermum scrub land. L. scoparium, Cassinia, Discaria, on hot dry ground.

Leptospermum seedlings are strongly light demanding and only appear on open ground. The shrub usually fails to regenerate and branching and death open the canopy sufficiently to permit the growth of shade tolerant tree species. Its value lies as an indicator of changing conditions. Cranwell (1936) also considers that Leptospermum is indicative of unstable conditions.

Coprosma species occur almost everywhere. They are particularly common, however, in the scrub above the treeline, and presence of their pollen could point to conditions similar to those prevailing in these zones today.

Trends shown by individual types.

1. Nothothofagus.

Nothofagus cliffortioides is characteristic of a cool and relatively dry climate. (Cockayne 1926 and 1928, Holloway 1949, Cranwell 1936). This being so, the presence of considerable percentages of Nothofagus is a reliable indication that the climate has been of this type.

The curve for Nothofagus shows that the climate was apparently cold and dry in Zone I and became unsuitable for beech in Zone II, which resulted in beech pollen dropping to about 1%. Following this the climate steadily improved for beech, until it attained an optimum when beech pollen forms almost 100% of the arboreal Pollen Presumably, at this time beech must have occupied almost all the locality. (This is borne out by the present extent of the forest, and, more particularly, by its even greater extent in early European and the immediate pre-European periods, when it occupied almost all the area below the tree-line (Burrows 1958).

The interpretation of the early part of the curve in Zone I is open to question, however. Many parts of the Waimakariri catchment are considered to have been invaded primarily by a mixed broad-leaf-conifer forest which moved up from the extensive forests of the plains, as soon as conditions ameliorated sufficiently after the retreat of the glaciers. (Speight, Allen, Holloway, Burrows). Before invasion by this particular forest association a mosaic of grassland, and scrub, prevailed (referred to as "Steppe conditions" by Cranwell and von Post 1936). If this hypothesis is correct it is difficult to reconcile it with the relatively high percentage of Nothofagus pollen. There are three possible explanations for the presence of this pollen. They are:

1. That Nothofagus cliffortioides forest was present in the immediate post glacial.
2. That the pollen belonged to Nothofagus fusca, which cannot be separated from N. cliffortioides.
3. That the pollen was windblown from sources outside this region.

There is some support for each assumption, but each has points against it also. The percentages of Nothofagus pollen are too high for it to be all dismissed as long distance pollen (Faegri and Iverson 1950, Dimbleby 1957). Harris (1953) mentions that slides exposed in Wellington city while beech was known to be flowering on hillsides around the harbour, picked up very few beech pollen grains. Bluell (1947), as mentioned earlier, found that only one quarter of a mile from the forest, the bouyant Pinus banksiana pollen rain had fallen to one tenth of the frequency in the forest itself. With these two examples in mind it seems unlikely that Nothofagus pollen would be carried in any quantity from distant sources. Small traces would no doubt be carried by wind, but not the high percentages encountered.

If the pollen was wind-blown the obvious sources would be from either the plains beyond the glaciers, to the south-east, or from the less-glaciated Hurunui River system to the North-east. There are objections to these sources. If the mountain beech was displaced in the direction of the plains by glaciers, one would expect this to have occurred throughout the Canterbury river system. However, some rivers have almost no beech e.g. the Rakaia River whose watershed is contiguous with that of the Waimakariri, to the South. (The Rakaia has beech in tributaries which communicate with the Waimakariri by low saddles). If beech had been displaced and then recolonised the Waimakariri from downstream, one would expect the same situation to occur in the Rakaia. As it has not in the latter case there is no reason why it should have in the Waimakariri River. Presumably then the source did not lie on the plains. However, it is quite likely that partial displacement took place, and Nothofagus cliffortioides occupied much of the grassland in the Castle Hill region, a few miles to the South-East. The absence of beech in most of the catchment of the Rakaia can be explained by assuming that more severe glaciation completely eliminated all traces of it.

The alternative hypothesis- that the pollen came from the North East in the Hurunui is possibly partly correct. Against this is the fact that most of the beech found in the Hurunui River is <u>N. Fusca</u> (Holloway 1952). This means very little, as N. fusca could be a recent element in the Hurunui flora. The winds at Cass are predominantly North-westerlies or South-westerly. Nurse (1958) explains the very frequent occurrence of "Nor-westers" at Cass as the down-flow of cold air from the mountains to replace warm air from the plains. As the mountains were presumably at least as cold in the immediate post-glacial as now, these winds would blow just as vigorously then as now, and would blow pollen from the Hurunui away from the Cass region. The other main wind, the South-westerly, is diametrically opposed to a pollen flow in a North-east to South-west direction. Therefore it seems unlikely that more than a trace came from the Hurunui.

As the proportion of beech pollen found in each sample remains fairly constant, and is too high for long-range wind dispersal, it points to the local presence of Nothofagus during the immediate post-glacial.

Conifers.

Dacrydium bidwillii and D. biforme are, as is stated in the ecological notes, species which are characteristic of cool and very wet conditions. The presence of their pollen in such numbers on the curves could represent either (1) a large scale colonisation of the area in a short time, or (2) a dense local representation on the moraines surrounding the bog. Dacrydium bidwillii is still present on bogs on Woolshed Hill about 3 miles west. As it presumably sheds its pollen directly onto the bog it could lead to over-representation. Dacrydium biforme is not now represented in the immediate district (Philipson and Brownlie 1958) but is present at Arthur's Pass. Therefore, if the pollen is mainly D. bidwillii it may be mere over-representation of a common bog-shrub, or, if it is D. biforme it could be a pointer to colder and wetter conditions.

These possibilities will be discussed more fully later. Cranwell (1936) considers Dacrydia to represent local bog culminations.

Phyllocladus alpinus is common in cool wet conditions. It is always present in the profiles, but usually as a minor constituent. This is in conformity with its present distribution as a zone at the upper limit of the beech forest in most places. However, at 240 cms depth in the bog its pollen amounts to 90% of the A.P. An explanation is that conditions were such that Phyllocladus thrived over most of the area and displaced most other species. This explanation would point to a climate of high rainfall and low mean temperatures.

Podocarpus totara, P. hallii, P. nivalis, P.acutifolius. Pollen in this group is probably mainly P. hallii and P. nivalis. These two are still members of subalpine forest and scrub in the Waimakariri catchment. P. totara is not known from closer than Banks Peninsula, but did at one time form part of the forests of the plains and downlands bordering the plains. P. acutifolius is found in Westland forests but not in the Waimakariri as far as is known. P. hallii, P. totara and P. nivalis both occupy a fairly wide range of habitats. P. hallii is fairly common in cool wet forests, and often occurs in the beech forests at Cass as a relic species which is not regenerating. P. nivalis is common on exposed well drained shingly slopes on most mountainsides in the region. Hybrids between P. hallii and P. nivalis are common and examples are found far from any present P. hallii. (Burrows Pers. Comm.) If the pollen grains present represent these then they indicate a flora which requires cool wet conditions. P. spicatus and P. ferrugineus still occur at the mouth of the Waimakariri Gorge and near the Kowhai River. As they grow and spread only in warm wet conditions the specimens in this region are relics of the great forests which once covered the plains, and presumably, as the presence of their pollen indicates, spread up the Waimakariri to near Cass.

Coprosma is the dominant pollen at one part of the profile. Without knowing the species it is unwise to attach importance to correlations between its presence and past climatic conditions. However, various species of Coprosma are a major part of sub-alpine scrub zones above the bush-line. Philipson and Brownlie (1958) note the occurrence of several species in this zone at Cass.

It can be postulated then that a high proportion of <u>Coprosma</u> pollen and hence <u>Coprosma</u> species points to conditions similar to those in this zone today - i.e. cold, wet and exposed. This is supported by Cranwell and von Post.

As pointed out previously <u>Leptospermum</u> is a shrub which commonly occupies ground left bare by the retreat ~~/~~of other species because of changing conditions. It does not grow in very cold conditions and so its absence in the lower part of the profile could point to near alpine temperatures. The greater frequency at 200 cm could be correlated with the unstable conditions resulting in a change from a cold <u>Phyllocladus sp.</u> - favouring climate to a warmer <u>Podocarpus species</u> - favouring climate.

On the other hand it could be part of a succession from swamp to bog to bog-scrub (Cockayne 1928) where <u>Leptospermum scoparium</u> invasion is a normal part of the drying of the ground. The high peak at 40 cm in comparatively recent times is unlikely to correspond with any drastic climatic change. It can also be interpreted as being again part of the drying out of a bog. <u>Leptospermum</u> is common around the bog at present.

The species of grasses represented by the pollen are not known. Pollen curves for the sedges and grasses do not present any marked changes throughout the profile but their greater frequency at the base does not contradict the generally accepted (Speight, Cockayne, Cranwell) hypothesis that cold and fairly dry conditions existed in the late glacial and early post glacial.

Floral History

The retreat of the Poulter ice advance from the Cass Valley left a moraine, bare of any vegetation, in the area South-east of the present site of Lake Sarah. As mentioned in an earlier chapter this kettle-hole bog probably came into existence as the buried ice melted over a period of a few hundred years.

How much of this moraine would have been colonised by this time is hard to ascertain. Certainly the moraines left by the retreat of present day glaciers are soon invaded by plants (Cockayne 1928) but climatic conditions near these glaciers are presumably more mild than they were in the immediate post-glacial times.

Pollen grains are sparse in samples below 380 cms. this could indicate that there were few plants growing in the vicinity of the bog, or that there were no plants at all, and that the pollen at this level was wind transported from some distance. The evidence supports the former view. Examination of the peat disclosed monocotyledonous remains, presumably sedges, which were too large to have been carried by the wind for any distance. The pollen spectrum at this level showed the presence of grasses, sedges, Coprosmas, Haloragidaceae, and various trees. The plants represented by these pollen types are those which one would expect to find on bleak recently colonised moraine.

The tree pollen provides a greater problem as, although the number of grains is few, proportionately it forms a considerable part of the total pollen.

Cockayne (1921) and Willet (1950) are probably correct when they say that forest was driven out of the mountains onto the plains by glaciation and lowering of the snowline. Presuming that beech forest spread at much the same speed then as now, it is feasible that the interglacial interval between Blackwater II and Poulter glaciations saw a readvance of the forest from the plains into Castle Hill basin, and that the latter advance may not have been sufficiently severe to drive it back again. Further spread westwards as conditions improved, and over the low saddles separating the Esk tributary of the Waimakariri from the less glaciated Hurunui system could also have begun.

The spread of grasses, sedges, and some small shrubs on to the abundant bare ground was probably rapid, - much faster than spread into the present closed communities prone to grazing is today. Differential migration rates of Nothofagus spp. and some conifers, (Dacrydium biforme and bidwillii and Phyllocladus alpinus) could have resulted in the conifers arriving first.

Coprosma is the dominant scrub-type present. Dracophyllum spp. are unexpectedly absent, except for one doubtful identification. As it has a large tetrad pollen grain often found in peat it was probably really absent.

Possibly its rate of dissemination is slower than that of Coprosma spp. and others found at this level.

Those conifers most likely to occur in periglacial conditions (Dacrydium biforme and D. bidwillii - particularly the former) reached a brief dominance before they were replaced by Phyllocladus.

Phyllocladus alpinus forest, apparently thriving in the prevailing climatic conditions and lack of competition from other forest trees spread rapidly and was the dominant feature of the landscape for some time.

With the decline of the Phyllocladus alpinus forest, Nothofagus spp. and Podocarps (including Podocarpus spicatus, ferrugineus, P. halli, and P. nivalis) appeared as the main constituents of the forest. If, as their pollen indicates, they were present in roughly equal proportions, it is probable that the Podocarps had filled the more favourable and moister sites in the valleys, while Nothofagus was moving on to the drier slopes and ridges of the mountains. Harris (1954) mentions that warmer elements tend to be under represented, so that if this is true for this region Podocarp forest may have been more extensive than the pollen frequencies indicate.

Finally Nothofagus cliffortioides became, as it is today, the dominant forest type. It is likely that there were two species of Nothofagus present whose pollen cannot be distinguished. N. fusca may have moved in first and been replaced by N. cliffortioides. Relict podocarps are found in the bush.

Phyllocladus as its pollen would indicate, still remains in the colder and wetter localities.

Many herbs and ferns are represented in small numbers throughout the profile, and presumably occupied much the same ecological niches, around and in the forest as they do today.

Leptospermum scoparium grew extensively on and around the bog at various times - particularly during the transition from Phyllocladus to Nothofagus/Podocarpus forest. Recent growths of L. scoparium could result from the destruction of vegetation by burning, mainly as a result of human activity.

Climatic changes.

The nature of the climatic changes is inevitably the most difficult to establish of all the aspects arising from analysis of this kind. Necessarily it must use indirect evidence and most of the evidence, being biological, is more indefinite than physical data. Postulations of former climates, based on plant evidence, must assume that plants in former times had ecological requirements similar to their present ones. It can make little or no allowance for ecotypes such as certainly exist in this region, and must draw on the very inadequate data available on the autecology of the involved species. Faegri (1956) quotes and emphasizes Fayerlind's statement:- "it is very hazardous to draw conclusions from the diagrams. Need caution, intimate knowledge of the plants in question, and ecological conditions of the area investigated".

Beenhouwer (1953) correlated species range with the Thornthwaite system of climates to see if palynological data could give an accurate index of climate. He found that use of a climatic classification would serve only as a guide by setting up the extremes within which the climate must have fallen. He thought it necessary to use general terms - warm, wet, etc.

All that can be attempted here is an outline of evidence which will support a postulated climatic change, and comparison of this evidence with evidence from other sources.

It is safe to assume that at the beginning of this period, dating from the retreat of the Poulter Ice Advance (Gage 1958) there were conditions of cold temperate and almost certainly, if existing glacial climates are considered, high precipitation. If these conditions prevailed, the snowline would be lower and more persistent than it is today.

It is probable that the amelioration of the climate - the rise in temperature - which caused the retreat of the glaciation, would continue. A rise of 8^o in the mean annual temperature would raise the snowline 5000 feet (Wilmott 1930). A lesser rise of only a few degrees would cause the gradual retreat of the glaciers. While the glaciers were retreating they would still exert a considerable cooling influence over the climate (Potzger and Courtemanche 1954).

Most former writers on this subject postulate a rise to an optimum temperature followed by cooler and drier conditions. Their findings are summarised in the following table.

Author	Year	Material	Conclusions
Hutton	1892	Moa remains in swamps	Wetter than now
Cockayne	1905	Discaria study	Wetter than now
Ferrar	1905	High level antarctic moraines	Warmer than present
Speight	1911	Totara remains	Wetter than present
Speight	1916	Buried Christchurch forest	Regional climatic change
Speight	1919	Moa distribution	First dry then wetter
Allan	1926	Forest pattern Mt. Peel	Formerly wetter

Author	Year	Material	Conclusions
Raeside	1948	Totara remains	Warmer than present
		Discrepancies between soils of Canterbury and Otago	Wetter than present
Raeside	1948	Higher timber line	Warmer than present
		Structural features and soil sequences on plains	Aggrading and degrading of soil levels probably associated with climatic and vegetational changes
Holloway	1954	Forest patterns	Recent deterioration.
Harris	1955	Pollen Pyramid Valley	Cooler and Drier

The plants represented by their pollen support this evidence but are not completely conclusive. To be conclusive it is necessary to argue from their present geographical range and to know for certain that the species are in equilibrium with the climate. Those found in Zone I could all be species which would tolerate cold conditions. Although it has been suggested (Speight 1919) that it was also dry the evidence available does not support this assumption as the genera represented have species common in moderately wet conditions.

A gradual amelioration of climate up to a post glacial optimum seems probable from the weight of the evidence. A slight rise in temperature of a few degrees would have produced climatic conditions favouring those species represented in the peat deposit. The regional rise in temperature would increase evaporation from oceans, etc., so rainfall would also rise. As it became warmer trees replaced the subalpine type scrub - first the cold and wet tolerant Phyllocladus alpinus, and then other Podocarps and Nothofagus.

A climatic optimum is shown by the presence of such thermophiles (in the local sense) as Podocarpus spicatus/ ferrugineus and doubtfully P. dacrydioides. The occurrence of Hymenophyllaceous spores at the same level as Podocarpus spicatus/ferrugineus support the evidence that it was then wetter than now. Associated with these were doubtless many of the species still found as relics.

Few of these associates are represented by their pollen, it may have been too sparse or local in distribution to have been encountered, or it may not fossilize. If the presence of these species as relics surviving from the warmer wetter podocarp period is accepted, then for a long period of time there must have existed in the locality, favourable microclimates. This seems reasonable, the present scarcity of species in this category being attributible to grazing of seedlings.

After this optimum, mean temperatures declined by perhaps two degrees. That the resultant climate was cooler and drier is shown by the intensifying dominance of Nothofagus spp. The more mesophytic N. fusca being replaced by the more xerophytic N. cliffortioides. Where it is protected from stock depredations regeneration of beech is prolific, showing that it is still in equilibrium with the present climate.

There is little definite evidence from the diagrams of the "Little Ice Age" of the Northern Hemisphere. There are different interpretations possible for this ommission.

The first is that the upper layers of this bog have been either decomposed by atmospheric activities, destroyed by fire, or perhaps, as the surface is slightly higher than the drainage outlet, never been formed. If this is the case then the upper layer of peat would have been formed prior to this event. A small piece of charcoal in unconsolidated peat a few inches from the surface showed that the surface had been burnt, but how recently is not known. Several fires have swept through parts of the valley since European settlement.

Secondly, the climatic changes near the beginning of the last millenium, may not have been sufficiently severe to have effected any profound floristic changes of a kind which leave definite evidence in pollen investigation, on the extensive Nothofagus forest of the area. Holloway (1954) has quoted the presence of relict matai and Nothofagus fusca from parts of these ranges as indicators of former wetter climates in recent times. In support of this there have been two lesser increases in the frequency of pollen of this kind since the main Podocarp maximum, of which the latter could be indicative of the milder period preceding the last climatic deterioration. As this latter frequency increase of Podocarpus spicatus/ferrugineus pollen occurs about halfway between the surface and the Podocarp maximum, the assumption that the rate of peat deposition has been fairly constant would place the time of the most recent climatic amelioration between one and two thousand years before the present, a time not irreconciliable with Raeside (1948) but perhaps earlier than that implied by Holloway's (1954) deductions.

Much of Holloway's results are based on localities with wetter and/or milder climates than the upper Waimakariri Valley, so that thermophilous indicator species (matai) may have persisted after the Cass forests had reverted completely to beech.

There is little evidence from this region to support Holloway's contention that much of the mountain country was occupied by a Hall's totara / Libocedrus community, and that Nothofagus forest survived only at the higher altitudes. Libocedrus pollen does not seem to fossilize, and pollen of the P. hallii/nivalis type is always numerically inferior to that of Nothofagus.

Harris's (1955) results for Pyramid Valley similarly provides evidence of a minor and recent climatic deterioration. Although his diagrams differ considerably, as altitudinal differences, etc., would lead one to expect, he also found no clear evidence of a major change in the conifer and beech pollen frequencies.

Raeside (1948) and Speight (1911) cite the evidence of totara logs to show that forest of this type was in existence only a few hundred years ago, in Canterbury in regions now free of forest. Recent $Carbon^{14}$ dating shows that these are older than expected - 1450 ± 70 years for wood from the outside of the log. (Ferguson and Rafter 1957). If it is accepted that these logs are those of the last surviving trees, this would push the time when these forests flourished and spread back into the period accepted as climatically optimal in the Northern Hemisphere - the last few thousand years B.C., and that cooler and drier conditions induced a decline culminating in extinction of this type of association in these localities more than 1000 years ago. Admittedly the present analysis gives little evidence pertaining to totara, but the definitely wetter climate of this intermontaine valley would be paralleled by higher rainfall on the outer ranges where P. totara remains are found.

Variations of topography, however, could result in favourable climates so that the forest persists on into more recent times, e.g. Banks Peninsula forests.

Botanical evidence contradictory in a broad sense to evidence of climatic change from many fields in the Northern Hemisphere is not present, but only further work will show whether the proposed outline is justified.

Correlation with Climatic Changes in other Regions.

Von Post's division of Post-glacial time into:

1. A stage of approach of a warm period
2. A stage of culmination of these elements
3. A stage of decrease of the characteristic trees of the warm period and return to the dominant forest constituents of today was used to replace the periods of Blytt and Sernander with a more generalized picture applicable to both hemispheres. That he was correct in considering both hemispheres has been supported by the Report of the Committee of Glaciers (1946) which decided that causative climatic variations affected both hemispheres and that variations were synchronous.

In Europe the climatic changes have been carefully investigated in many fields - historical, stratigraphical, zoological, palaeobotanical, palynological, and biogeographical.

In New Zealand work has been limited to a few scattered localities which are probably greatly affected by topography and proximity of oceans. So far in New Zealand it has not been possible to decide upon definite horizons or pollen zones which makes synchronization of profiles from different places possible. Only broad similarities are visible so far, but it possible to show that they are comparable with Northern Hemisphere changes.

The following table shows a tentative correlation of British late and post-glacial events with those resulting from this analysis.

Dating (British)	Vegetation: British Isles	Vegetation: Waimak N.Z.	Forest Cover: British	Forest Cover: N.Z.	Climate	Peat	Blytt & Sernander	
present	Alder-Beech Oak-beech	Beech	cleared by man		Deterior-ation	peat depos-ited	sub-Atlantic	Post-Glacial
B.C.								
2000	Alder mixed oak forest	beech mixed Podocarp	Forest		Climatic		sub-Boreal	
4000	Hazel-pine	Podocarp Phyllocladus	Forest		Optimum		Atlantic	
6000						Organic muds	Boreal	
	Birch	Phyllocladus Dacrydium			Ameliorat-ion		pre-Boreal	
8000 10000 12000	Open woods Park-tundra	"steppe" conditions			cold milder cold		Upper Dryas Allerød lower Dryas	Late Glacial

Harris gives a similar comparison of Pyramid Valley pollen results and North west Europe. His carbon datings agree fairly closely with European Zone datings.

amid Valley tion	N.Z. Pollen Zone	N.W. Europe Climatic Series	Recurrence Surfaces
eat			
Clayey Marl-Gyttja	Beech Forest	sub	400 A.D.
Marl Gyttja	111 Cooler drier	Atlantic	
	Drier N. fusca		111 600 B.C.
Clayey Marl Gyttja			
		Sub Boreal	IV 1200 B.C.
Peat	11 Podocarp	Atlantic	2300 B.C.
Limey Silt			
Sandy Clay	Steppe	Boreal	
		Pre Boreal	

es from Pyramid Valley.

p contents average 670 years
ut 5ft. in Marl.

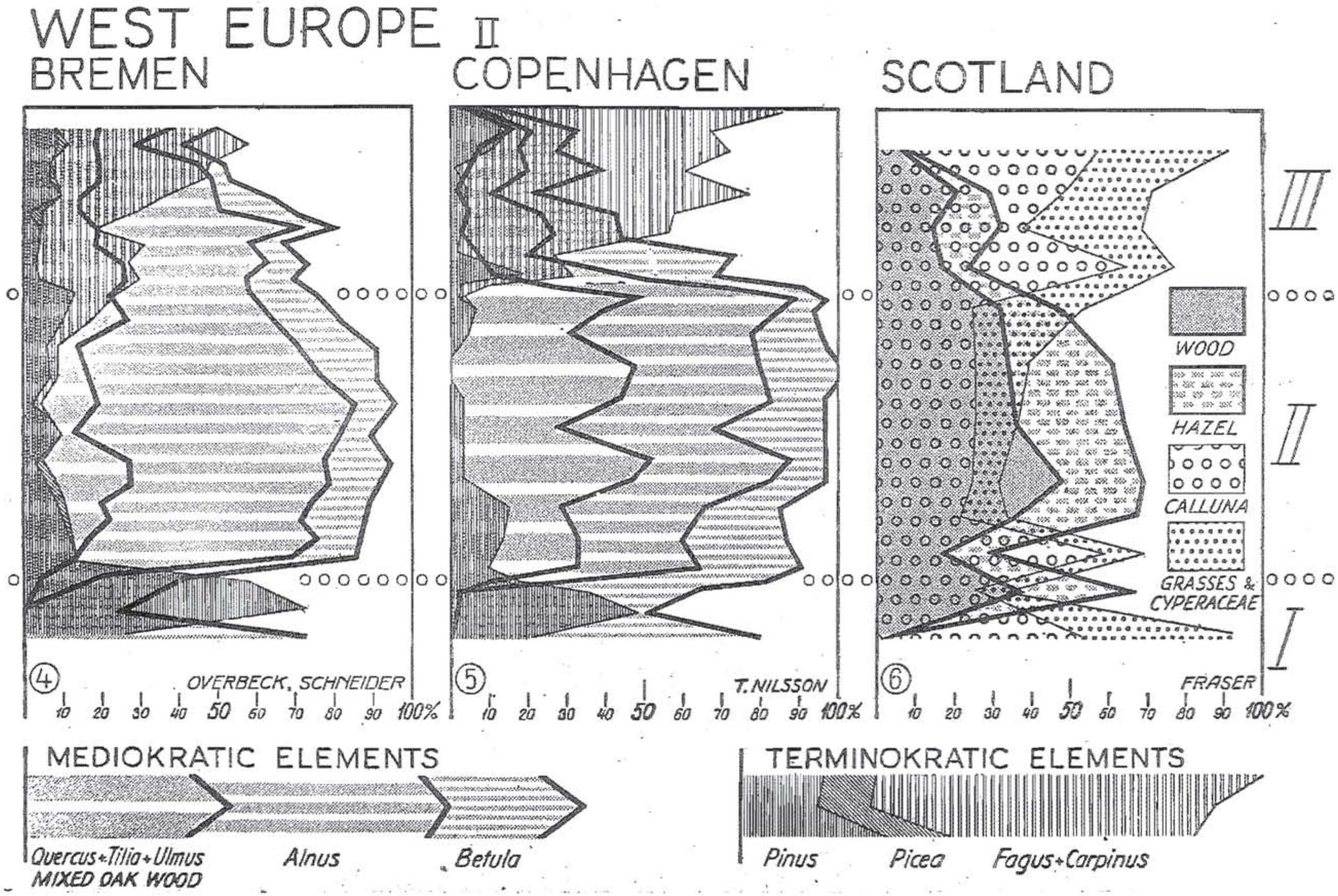
Assumption that moder
shell has more c14
than modern wood

rl Matrix	Av 560	
per Marl 3ft	Av 2750	3550
wer Marl 4ft 3in	3400	4150
ayey Marl 5ft 3in	4300	5100
at underlying per lake 6ft. 3in	3650	

Von Post proposed a system utilizing mediocratic and terminocratic elements to demonstrate regional parallelism. Mediocratic elements in this region

Synchronized Pollen Diagram Chain

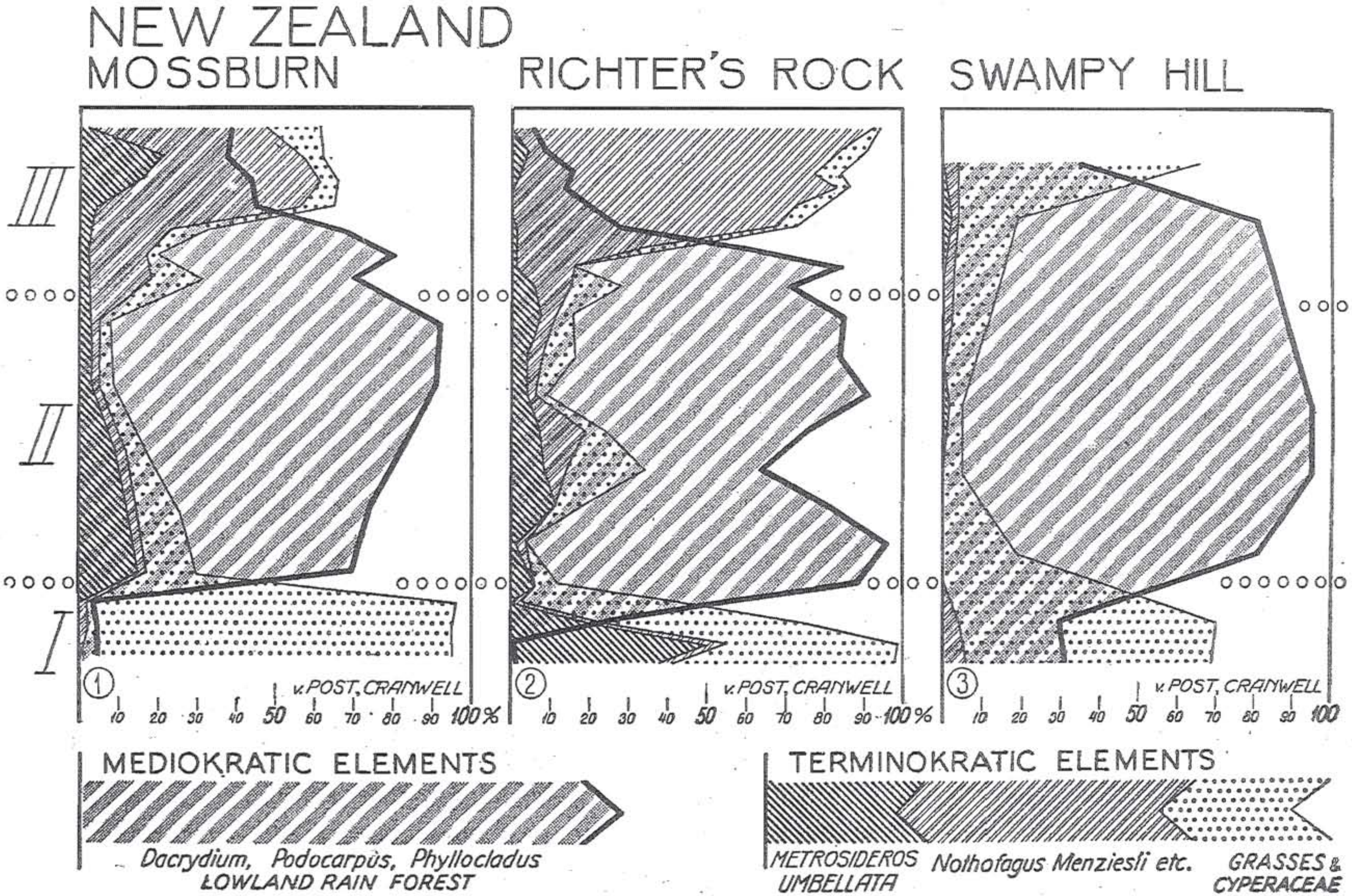
from West Europe


WEST EUROPE II
BREMEN
COPENHAGEN
SCOTLAND
III
II
I
WOOD
HAZEL
CALLUNA
GRASSES & CYPERACEAE
④ OVERBECK, SCHNEIDER
⑤ T. NILSSON
⑥ FRASER
10 20 30 40 50 60 70 80 90 100%
MEDIOKRATIC ELEMENTS
Quercus+Tilia+Ulmus
MIXED OAK WOOD
Alnus
Betula
TERMINOKRATIC ELEMENTS
Pinus
Picea
Fagus+Carpinus

<u>Synchronized Pollen Diagram Chain</u>

<u>from Southern part of</u>

<u>New Zealand</u>

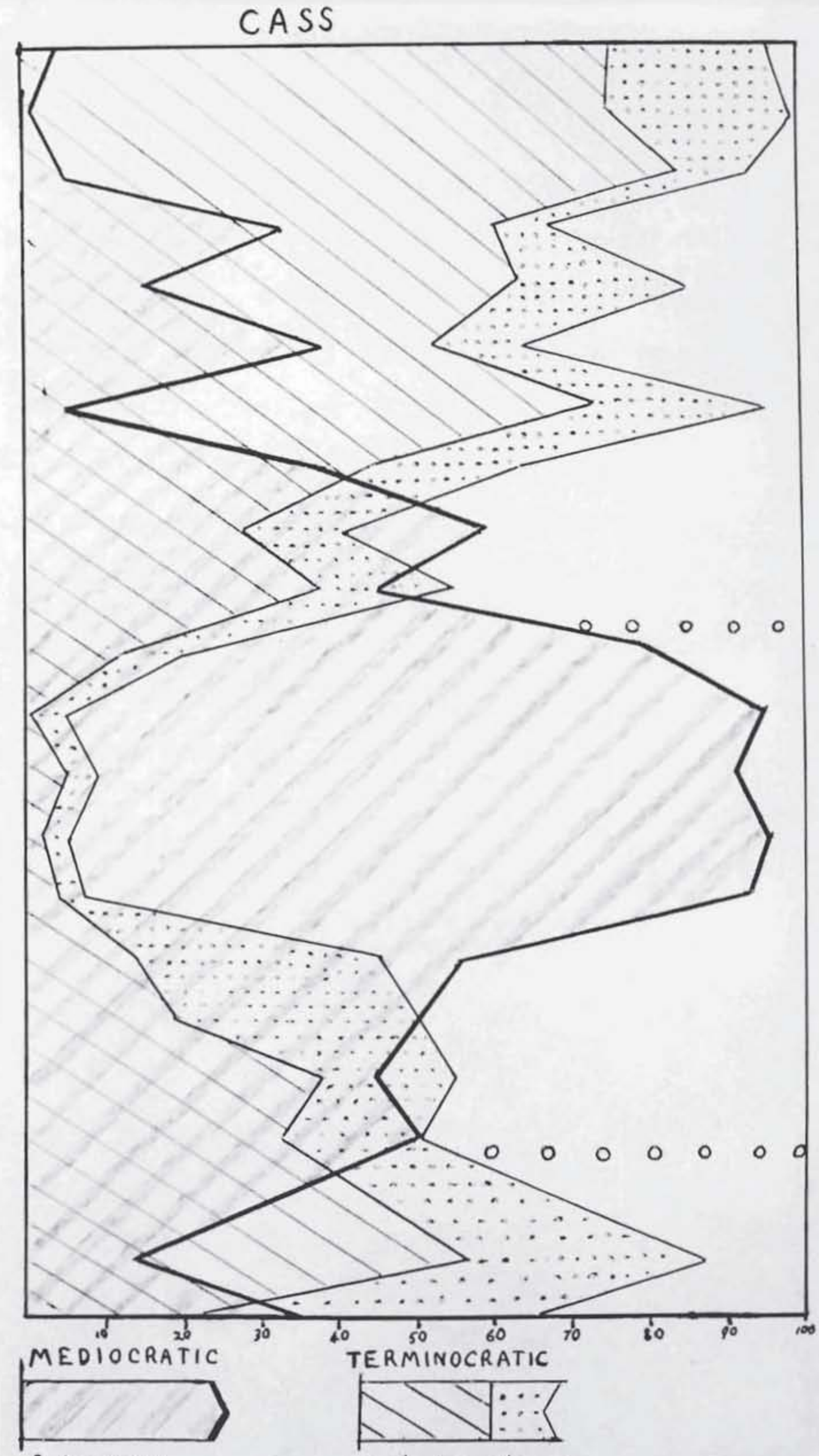


NEW ZEALAND
MOSSBURN
RICHTER'S ROCK
SWAMPY HILL
III
II
I
v. POST, CRANWELL
10 20 30 40 50 60 70 80 90 100%
MEDIOKRATIC ELEMENTS
Dacrydium, Podocarpus, Phyllocladus
LOWLAND RAIN FOREST
TERMINOKRATIC ELEMENTS
METROSIDEROS UMBELLATA
Nothofagus Menziesii etc.
GRASSES & CYPERACEAE

Pollen Diagram from Cass, N.Z.

showing comparable Regional

Parallelism and Revertence


CASS
III
II
I
10
20
30
40
50
60
70
80
90
100
MEDIOCRATIC
TERMINOCRATIC
Podocarpus
Dacrydium
Phyllocladus
Nothofagus/Grass
Sedge

include Dacrydium spp., Podocarpus spp. and Phyllocladus sp. Terminocratic elements are Nothofagus spp., grasses and sedges. Regional parallelism can be defined as the same scheme of structure recurring in pollen diagrams within one geographical region after another, but that every stage of development is represented by different plants within these regions. As the figures show, fundamentally this pollen diagram gives much the same basic figure as three Northern Hemisphere diagrams and also agrees with those from Otago and Southland. In all cases there is revertence to the original floral types after a period of dominance by plants indicative of a milder climate.

Conclusions

1. The organic mud in the lower parts of the bog shows that it started as a small lake which gradually filled in and became a Sphagnum - sedge peat bog.
2. Pollen grains found in the organic mud indicate that the area surrounding the bog had primarily vegetation tolerant of cold "steppe" conditions.
3. Remains in the peat of Podocarps point to an invasion by forest of mesophytic affinities.
4. There has been a resurgence of beech forest, and decline of the Podocarps in recent times.
5. From the associations of plants found in these three zones certain inferences can be drawn regarding the climates prevailing during the times of deposition.
6. The inferences possible are - (a) that the climate was cold, and probably wetter than now. (b) That an amelioration occurred to a climate warmer and wetter than the present. (c) There has been some reversion towards a colder and more arid climate.
7. The relatively high proportion of Nothofagus could be fortuitous, and result from long distance wind transport, but is just as likely to be indicative of the presence of beech in nearby localities not

affected directly by glaciers.

8. These results agree broadly with those relating to climatic changes, obtained in other fields in New Zealand.

9. These findings support von Post's concept of regional parallelism: They can be correlated broadly to changes in the Northern Hemisphere and to changes in Otago.

Summary

A pollen analysis of a profile from the deepest part of the Kettlehole bog in the Cass Valley, Waimakariri River, yielded pollen which showed that there has been a change from grass-sedge association (with perhaps some trees), through a period when Podocarps formed one of the major elements of the forest, to the present predominantly Nothofagus forest. Inferences regarding climatic changes arenot at variance with most results from other sources, except in that changes may have taken place earlier than believed by some workers.

Sampling and Preparation of material for examination

Samples for laboratory examination were taken at the deepest part of the bog. Potzger and Wilson (1945) showed that unless borings are taken at this point they are truncated and do not record the earliest forest history.

A Hiller peat auger, was used, and samples were taken every 5cm from the surface to the gravel on the bog's bottom.

Great care was taken to ensure that samples were not contaminated by peat from other levels. After a sample from each core had been removed and placed in a numbered polythene bag, the remainder was examined for mineral content, degree of humification, and water content.

These results are shown in tabular form.

In the laboratory a small amount of every fourth sample was processed as follows:

As the quantity of pollen per gram of peat was not relevant the sample used was not weighed.

1. About 2 grams of peat were placed in a numbered centrifuge tube.
2. 10% potassium hydroxide solution was added until the liquid level rose to the 10c.c. mark.
3. This mixture was placed in a boiling water bath for six minutes.

4. It was centrifuged, the dark liquid decanted, and centrifuged twice more with water.

5. Acetolysis. Dehydration with glacial acetic acid and centrifuging preceded this.

6. Acetolysed for 1 minute in a $100^{\circ}c$ water bath with a freshly prepared 10c.c. acetic anhydride: 1c.c. concentrated sulphuric acid mixture. (half this was used for each sample). Centrifuged for some time while hot.

7. Washed and centrifuged twice with water.

8. A small quantity was now transferred to a slide, a fragment of glycerine jelly added, and warmed. When it had melted a cover-glass was placed over it, and the slide labelled and set aside.

   No staining was considered necessary as the pollen grains were quite dark in colour.

   Usually two samples were processed simultaneously.

   Strict attention was paid to cleanliness of apparatus at all times to avoid risk of contamination.

From the surface down to sample 60 (300cm) mineral matter caused no interference but below this level samples were badly obscured. Hydrofluoric acid treatment, to remove siliceous matter was necessary.

Method. After KOH treatment and before acetolysis the sample was boiled for two minutes in 40% Hydrofluoric acid in a copper crucible. The crucible contents were then tipped in 20cc of 7% Hydrochloric acid and centrifuged in Pyrex tubes. Further washings in 7% Hydrochloric acid and in water followed. (All work with Hydrofluoric acid was done in a fume cupboard).

A differential flotation method in a bromoform/acetone solution relying on the different densities of pollen and clay met with no success (Frey 1955). Presumably the clay (loess) found at Cass has a density too similar to that of the pollen grains for the method to work. Dimbleby (1957) reported that this method was little use with silt.

Table of Numbers of Pollen Grains

Cm.	Nothofagus	Pod.spic/fer.	Pod.hall/niv.	Pod.	Phyll.	Dac.
20	154		1	2	4	
40	164	1	1			
60	273	4	8	4	3	
80	98	35	4	9	7	
100	152	16	8	10		
120	138	64	5	15	16	
140	230	4		3	9	
160	87	31		20	22	
180	53	68	2	21	33	
200	76	23	1	8	56	1
220	22	9	1	7	125	2
240	2	8	4	4	140	3
260	11	1	5	1	165	1
280	4		8	1	145	30
300	7		5		45	115
320	4		4		9	3
340	5		3	1	9	
360	48	12	7	2	35	
380	12		5		13	1
420	5		7		3	1
440	6		5	2	3	

Where tree pollen is sparse the figures given are the result of counting many slides. Pollen was almost completely absent from some samples.

Cm.	Umbell.	Halor.	Filic.	Gram.	Cyper.	Lepto.	Copr.
20	4	4	1	12	33	19	6
40	4	3	1	13	40	90	1
60	1		2	4	28	2	2
80	2	5	2	7	14	5	5
100	2	9	2	19	31	8	8
120	4	9	8	10	16	1	3
140	2	7	1	13	57	6	5
160	9	6	4	19	19	13	6
180	6	4	1	10	17	12	8
200	7	3		14	21	24	2
220	8	3	4	8	7	19	9
240	4	1	1	4	3	1	7
260	1		1	2	3	1	8
280	2		1	2	3	1	23
300	4	1	3	3	3	1	30
320	4	1	5	8	1		105
340	3		5	7	1		110
360	5	3	50	17	5		26
380	1	1	46	5	2		37
400		2	86	15			9
420	2	17	3	13	8		18
440	2	3	2	9	3		18

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